PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improvements in or relating to Directional Antennas

We, WESTERN ELECTRIC COMPANY INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation of the State of New York, United States of America, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to directional antennas and particularly to directional antennas for use in radio location and like systems to which it is desired to impart a beam-sweeping action without varying the frequency of the waves or moving the antenna structure.

It has previously been proposed to make an aerial highly efficient in one predetermined direction by altering its transmission characteristic, as by loading, in such a manner that for signals proceeding to or from the wanted direction, the wave velocity and the phase of the waves in the aerial is substantially the same as that of the waves or the component thereof travelling parallel to the aerial in space.

In accordance with the invention a beam-sweeping action is imparted to a directional antenna provided with a wave transmission channel adapted to radiate or receive the waves at points along its length, by cyclically varying the phase velocity of the waves within the transmission channel. This variation in phase velocity may be conveniently produced by cyclically varying the effective cross-sectional area of the wave channel.

More specifically, the invention provides a directional antenna comprising a wave guide adapted to radiate or receive the waves at points along its length and a movable member interacting with the waves within the wave guide and adapted by its movement to produce a cyclical variation in the phase velocity of the waves and thereby impart a beam-sweeping action to the antenna.

The movable member preferably comprises a rotor of substantially cylindrical or partly cylindrical construction extending longitudinally within the wave guide and provided with a longitudinal slot or having a longitudinally extending flat surface, whereby the effective cross-sectional area of the wave guide is varied as the rotor rotates and the desired cyclical variation in phase velocity is imparted to the waves within the wave guide.

The antenna may be provided with a horn formed by adding extensions in the shape of right-angled triangles of conducting material to the magnetic plane walls, the right angles being at the end of the antenna to which the translation device is connected and one side of the horn being closed by a metallic extension of the end wall of the antenna. The horn is thus in the form of a "harp" with its open long side acting as the wave emitting or receiving aperture. Two such antennas, one for receiving and one for transmitting may be mounted one above the other so that their apertures lie in the same plane and, if desired, the receiving antenna only may be provided with a rotor.

As used herein, the term "phase velocity" denoted by v is the apparent velocity of the wave along the transmission channel; and the terms "velocity ratio" and "phase velocity characteristics", both denoted by k, refer to the ratio of the phase velocity c in free space to the phase velocity v, in the guide, the ratio $\frac{c}{v}=k$ being equal to the ratio $\frac{\lambda_a}{\lambda_g}$ where λ_a is the operating wavelength as measured in the air or ether and is designated herein the "ether wavelength", and λ_g is the operating wavelength as measured in the dielectric guide and is designated herein the "guide wavelength". For air-filled guides, v and λ_g are, respectively, greater than C and λ_a. Also, as used herein the term "transmission channel" generically includes a dielectric channel, such as a wave guide, and a line channel such as a two-wire or single-wire line.

Also as used herein, the term "leaky wave guide of the first kind" refers to a circular or rectangular wave guide having one or more antenna slots, usually one,

extending parallel to the longitudinal axis of the guide. The term " leaky wave guide of the second kind " refers to a circular or rectangular wave guide having a plurality of antenna apertures included in one longitudinal wall and spaced in a direction parallel to the longitudinal axis of the guide.

In one embodiment of the invention, a so-called " first kind " leaky metallic wave guide antenna is equipped with a substantially cylindrical rotor. A translation device and a line are connected to the guide for utilizing H_{01} waves and the longitudinal antenna slot is located in an electric plane wall of the guide. The rotor extends longitudinally within the guide and is positioned adjacent the other electric plane wall or side. The rotor contains a longitudinal slot and means are provided for continuously rotating the rotor. In operation, as the rotor revolves the phase velocity of the waves conveyed by the guide is cyclically varied, whereby the maximum direction of action of the slot or aperture antenna is oscillated through a desired azimuthal sector.

In a slightly different embodiment a so-called " second kind " leaky wave guide antenna comprising an air-filled rectangular guide having a plurality of transverse antenna slots or circular antenna apertures in one magnetic plane wall, is equipped with a rotor of the type described above, the rotor being positioned closely adjacent to one of the electric plane walls. Each transverse or circular aperture has an individual or unit antenna directive characteristic and the several slots or apertures constitute a linear array having a space factor directive characteristic. Preferably, the distance between the adjacent apertures is such that, with the range of velocities obtainable and with the selected rotor, the scanning sector may be positioned broadside. As in the embodiment first described above, the revolving rotor changes the phase velocity characteristic of the guide and, as a result, the space factor characteristic is cyclically oscillated across the major lobe of the unit characteristic. The dimensions of the rotor and of the rotor slot or aperture, are chosen so that a velocity variation range, dependent upon the spacing between the adjacent antenna apertures, is obtained which prevents the production of a second mode of lower velocity, and therefore prevents distortion of the space factor directive characteristic during its oscillation.

The invention will be more fully understood from the following description in conjunction with the accompanying drawings in which like reference characters denote elements of similar function and in which:

Figs. 1 and 2 are, respectively, perspective and transverse cross-sectional views of one embodiment of the invention; and Fig. 3 illustrates, in perspective, the rotor used in the embodiment of Fig. 1 and two alternative rotors;

Fig. 4 is a perspective view of a different embodiment of the invention; and Fig. 5 illustrates a measured receiving oscillatory directive characteristic for the embodiment of Fig. 4;

Figs. 6 and 7 are, respectively, a perspective view and a top view of a " radar " or radio location or like system in which the embodiment of Fig. 4 is utilized; and Fig. 8 illustrates the measured overall or " round trip " directive characteristics for the " radar " system of Figs. 6 and 7;

Fig. 9 is a perspective view of another embodiment of the invention; and Fig. 10 is a directive diagram used in explaining the system of Fig. 9;

Fig. 11 is a perspective view of still another embodiment of the invention; and Fig. 12 and 13 are, respectively, a schematic diagram and a set of curves used in explaining the embodiment of Fig. 11.

Referring to Figs. 1 and 2, reference numeral 1 denotes a rectangular air-filled metallic wave-guide comprising the flat electric plane or " a " wall 2, the concave electric plane wall 3, the magnetic plane or " b " walls 4 and 5 and the enclosed air dielectric medium 6. Numeral 7 denotes a translation device, such as a transmitter, a receiver, or a " radar " transceiver, the device 7 being connected to a coaxial line 8 comprising inner conductor 9 and outer conductor 10. The end portion 11 of inner conductor 9 extends through wall 5 and into the dielectric medium in a direction perpendicular to walls 4 and 5, whereby transverse electric or H_{01} waves represented by arrow 12 are emitted or collected by the exposed inner conductor portion 11. If device 7 is a transmitter the conductor portion 11 constitutes an " exciter " antenna element; and if device 7 is a receiver conductor portion 11 constitutes a " pick-up " antenna element. The front electric plane wall 2 is in a vertical plane and contains a horizontal longitudinal antenna slot 13. Reference numeral 14 denotes a hollow cylindrical or tubular rotor which extends longitudinally within guide 1 and is positioned closely adjacent the rear guide wall 3. The rotor 14 is supported near each end by the end walls 15 and contains a longitudinal slot or aperture 16. In one 10-centimetre system tested the rotor dia-

meter was about one inch and the slot width was about 1/32 of an inch. The rotor is connected through the drive shaft 17 to a motor 18, the shaft preferably but not necessarily including an insulator 19.

Assuming that device 7 is a receiver and that member 14 is not rotating, the rotor angle ψ (Fig. 2) being equal to 90 degrees, the operation of the system of Figs. 1 and 2 will now be explained. Wavelets emitted at a distance station or reflected by distance targets are collected by the slot antenna 13 and conveyed as H_{01} waves to the pick-up element 11. The collected wavelets are then conveyed by line 8 to the receiver 7. The wavelets received at any two discrete points therein as, for example, segmental antennas 20 and 21, have a phase relation, as collected, dependent upon the direction 22 of the incoming wave. If the direction 23 of maximum action for the slot antenna 13 coincides with the wave direction 22, the wavelets arrive in phase at the receiver and a maximum receiving effect is obtained. The phase velocity v in guide 1 is such that, with rotor 14 stationary, the direction 23 of maximum action of the slot antenna 13 makes an acute angle with the normal to the plane of the slot 13 as, for example, the angle $\Delta=30$ degrees, where the angle or direction $\Delta=0$ degrees is perpendicular to the plane of the slot. With motor 18 actuated the rotor 14 revolves and produces a variation in the phase velocity of guide 1, and the maximum receiving lobe including the direction 23 of maximum action, is caused to oscillate in the azimuthal plane through a given angular sector or angle $+\theta$ to $-\theta$ where $\theta=0$ is the mean or central direction of antenna action in the sector.

The theory explaining the effect produced on the phase velocity characteristic of the guide, by rotation of the rotor, is not fully understood. According to one theory, the change in phase velocity is caused by the cyclical variation of the cross-sectional area, and especially the transverse magnetic plane dimension "b" of the guide, since the frequency characteristic and the phase velocity characteristic are functions of the "b" dimension. This theory, however, is not entirely satisfactory since in certain structures the directive lobe moves more or less uniformly through the $+\theta$ to $-\theta$ sector and the change in cross-sectional or "b" dimension may not be uniform and, therefore, may not correspond to the lobe movement. According to another theory which appears plausible the velocity variation rotor is a variable impedance element which functions to change or disturb cyclically the impedance of the guide and therefore the guide velocity. In a more or less analogous manner, as explained in United States Patents Nos. 1,562,961; 2,145,024, (Fig. 1), and 2,236,393, the phase velocity of a conventional two-wire line may be increased by utilizing in the line a plurality of series condensers or shunt inductances, and may be decreased by utilizing shunt capacities or series inductances. Most likely the velocity change in the guide 1 is a result of several interrelated factors.

Referring to Fig. 3, numerals 24 and 25 designate rotors either of which may be used in the embodiment of Fig. 1 in place of rotor 14. As illustrated, the velocity variation rotor 24 is a solid metallic semicylindrical rotor having the flat surface 26; and the velocity variation rotor 25 is a solid cylindrical metallic rotor containing a longitudinal slot 27. Other rotors may, of course, be utilized in the system of Fig. 1.

Referring to Fig. 4, the antenna comprises, as in Fig. 1 an air-filled leaky wave guide 1 of the "first kind" having a longitudinal slot 13, a rotor 14 with a longitudinal aperture 16 (Fig. 1) and a motor 18 for driving the rotor. The guide 1 is connected to the translation device 7 by coaxial line 8. Numerals 28 and 29 denote a pair of parallel metallic right-triangular shield members spaced apart a distance equal approximately to the "a" dimension of guide 1. One edge 30 of member 28 is attached to the junction or linear corner formed by guide walls 2 and 4, and one edge 30^1 of member 29 is similarly attached to the junction of guide walls 2 and 5, in a manner such that the shields 28, 29 constitute, in a sense, extensions of the "b" walls 4, 5 of guide 1. Each member 28, 29 has an edge 31, 31^1 extending perpendicularly to the wall 2 and a hypotenuse edge 32, 32^1 extending perpendicularly to the mean wave direction $\theta=0$ degrees. Since the direction $\theta=0$ degrees corresponds to the mean phase velocity characteristic of guide 1, edges 30, 32 and 30^1, 32^1 members 28 and 29 form an acute angle which is related to the mean phase velocity in guide 1. Also, the aforementioned acute angle is equal to the acute angle Δ formed by the wave direction $\theta=0$ degrees and the normal to the plane of slot 13. In one system constructed in accordance with Fig. 4, and tested, the above-mentioned acute angle was 30 degrees. Numeral 33 denotes a side shield member included between the edges 31 of members 28 and 29 and attached to the junction of side wall 2 and one of the end walls 15 of guide 1. Thus, the arrangement or structure constitutes a "harp" antenna having a

wide rectangular antenna aperture 34. Numerals 35 denote transverse flanges or flared end-pieces and numerals 36 designate side or longitudinal flanges. The flanges 35 and 36 are attached to the four edges of the rectangular antenna aperture 34 and hence constitute a horn antenna.

In operation, Fig. 4, assuming device 7 is a receiver, pulsed centimetric waves are received, after reflection from a distant target, by the wide antenna aperture 34 and guided by shield members 28, 29 and 33 to the narrow secondary antenna aperture 13 in guide 1, and are thence conveyed as H_{01} waves to device 7. As rotor 14 revolves the phase velocity characteristic of guide 1 is cyclically varied and the direction 23 of maximum radio action is oscillated across the scanning sector bounded by the directions $+\theta$ and $-\theta$. In other words, since c is a constant and v varies cyclically in accordance with the variation in the rotor slot angle ψ Fig. 2, the angle or direction θ is cyclically varied. With the rotor angle ψ equal to 0 degrees, the highest phase velocity v is obtained and with the rotor angle ψ equal to 180 degrees the lowest phase velocity v is obtained.

While the vertical plane of the slot 13 is inclined at an angle to the direction θ the vertical plane of the rectangular antenna aperture 54 is perpendicular to the direction θ. Thus, in a sense, the shield members 28, 29 and 33 project the slot antenna aperture 13 into the vertical wave front plane for the direction $\theta=0$ degrees. Stated differently, the $+\theta$ and $-\theta$ scanning sector, or more accurately the mean direction $\theta=0$ degrees, is, relative to aperture 34, in the so-called broadside position. On the other hand, in the embodiment of Fig. 1, the azimuthal scanning sector is in the oblique position, that is, at an acute angle to the normal to the antenna slot 13. In addition, the shields 28, 29 and 33 function, in effect, to change or transform the narrow antenna aperture 13 into a wide antenna aperture 34 whereby the lobe width in the plane perpendicular to the scanning plane is decreased and the gain of the system is increased. As pointed out below, in the "radar" system of Figs. 6 and 7, the shields also prevent interaction between the separate transmitting and receiving antennas. The flares 36 function as a horn and further decrease the lobe width in the plane perpendicular to the scanning plane.

The curves of Fig. 5 were obtained during a receiving test of the system of Fig. 4. In Fig. 5 the lobe 37 shown in full line and having its principal axis or direction 23 aligned with the $\theta=-7$ degree direction, approximately, corresponds to the $\psi=0$ position (Fig. 2) of rotor 14; and the lobe 37 shown in dash line and aligned with the $\theta=+3$ degree direction, approximately, corresponds to the $\psi=180$ degree rotor position. During the test the velocity variation rotor 14 functioned to oscillate direction 23 of the maximum lobe 37 through the 10-degree sector bounded by the -7 degree and $+3$ degree directions. In this connection it is important to note that lobe 37 is not switched from the full line to the dash line position but moves, back and forth, across the sector, as indicated on the drawing by the two peaks of lobe 37 included between the full line and dash line lobe positions.

Figs. 6 and 7 illustrate a "radar" system comprising a transmitting "harp" antenna 38 connected by line 8 to the transmitter 39 and a receiving "harp" antenna 40 connected by line 8 to the receiver 41. The "harp" receiving antenna 40 is the same as that illustrated in Fig. 4. The "harp" antennas 38 and 40 differ primarily in that the transmitting antenna 38 is not equipped with a velocity variation rotor and each right-angle shield member 28, 29 has two 45-degree acuate angles, whereas the receiving antenna 40 is equipped with a velocity variation rotor 14 and each of the right-angle shield members 28 and 29 has a 30-degree angle and a 60-degree angle. The guide 1 of the 45-degree antenna 38 has a wider "b" or magnetic plane dimension than guide 1 of the 30—60 degree antenna 40, since the angle between the slot 13 of antenna 38 and its direction of maximum action is 45 degrees whereas the angle between slot 13 of antenna 40 and its direction of maximum action is 60 degrees. Also, the rear guide wall of antenna 38 is flat, whereas the corresponding guide wall of antenna 40 is preferably made concave, as described previously, to accommodate the rotor 14. The structures are superimposed so that their projected apertures 34 are included in the same vertical plane and their corresponding end flanges 35 are aligned. It will be observed that the gides 1 are connected to non-corresponding ends of the apertures 38 and 40 and the transmission lines 8 are therefore also connected to non-corresponding ends of the guides so that the energy in the two guides 1 flows in opposing or diverging directions 42. In other words the two antenna apertures have a reversed feed, as shown by arrows 43.

In operation, Figs. 6 and 7, pulsed centimetric waves are supplied over line 8 by transmitter 39 to antenna 38 and

maximum radiation occurs in a direction 44 corresponding to $\theta=0$ degrees and perpendicular to the rectangular aperture 34. The stationary maximum transmitting lobe is sufficiently broad to blanket or illuminate with radio energy the desired azimuthal sector bounded by the angular directions $+\theta$ and $-\theta$. Hence, pulses impinge upon all reflective objects disposed in the sector and are returned as echo waves to the receiving antenna 40. The motor-driven rotor 14 of the "harp" receiving antenna 40 causes the maximum lobe of the receiving antenna to oscillate and scan the $+\theta$ and $-\theta$ degree sector. More specifically, the maximum lobe, including the direction 23 of maximum action, of the receiving antenna 40, moves across the sector and the echo pulses are successively received, the receiver being preferably adjusted so that the directional indication obtained is related to the direction 23 of maximum antenna action rather than to a direction of minor antenna action. The transmitting antenna may, if desired, be equipped with a rotor for the purpose of oscillating the maximum transmitting lobe.

The direction 44, Fig. 7, represents the principal axis of the primary maximum lobe of the transmitting antenna 38 and the direction 23 represents the principal axis of the primary maximum lobe of the receiving antenna 40. These primary lobes are established by the so-called "go" waves in the guides 1 of antennas 38 and 40. In each of the guides 1 the "return" waves, reflected by the end wall 15 remote from the coaxial line connection, establish a pronounced minor lobe at an angle to the axis of the slot antenna 13 equal to the angle between the maximum lobe and the slot axis. In addition, in the case of each slot 13, one or more minor lobes having directions included between the maximum lobe and the slot axis are established by a component having a lower velocity mode. In Fig. 7, reference numerals 45 and 46 denote the principal axes of the pronounced undesired "reflection" lobes, and numerals 47 and 48 denote the principal axes of the undesired "lower velocity" lobes, respectively, for antennas 38 and 40. By utilizing a reversed feed for the two superimposed guides 1 of antennas 38 and 40, which antennas have their maximum lobe axes 23 and 44 superimposed or coincident, the lower velocity lobes 47 and 48 are displaced and in fact are established on opposite sides of axes 23, 44, so that they do not combine to form a pronounced overall or "round trip" lower velocity lobe. As is known, the overall directive characteristic for the system of Figs. 6 and 7 (see Fig. 8) is the product of the receiving and transmitting characteristics, that is, the ordinates represent the square root of the product of the powers of the receiving and transmitting antennas in a particular direction, the power being measured on an arbitrary scale in which the maximum power is considered as unity. Considering the reflection lobes 45 and 46, these lobes would not align if the reversed feed were not used, since the antennas 38 and 40 have dissimilar angles. The reversed feed, however, insures the establishment of these lobes on opposite sides of directions 23, 44. Hence a highly desirable overall characteristic having no pronounced minor lobes is obtained. The reversed feed necessitates, in part, orienting the two slots 13 at an angle, and the shields 28 and 29 function to prevent interaction between the angularly related slots. If antennas 38 and 40 had similar angles, and if the reversed feed were not used, it would be practical to include the slots 13 in the same vertical plane. In this case the shields 28 and 29 would not be necessary, and only horn flares, such as flares 36, would be required to prevent interaction.

Referring to Fig. 8 which illustrates the overall directive characteristic for the "radar" system of Figs. 6 and 7, reference numerals 49, 50 and 51 denote the positions of the lobe corresponding, respectively, to the rotor positions, Fig. 2, $\psi=0$ degrees, $\psi=90$ degrees and $\psi=180$ degrees. The lobe position for $\psi=270$ degrees is substantially the same as that obtained for the rotor position $\psi=90$ degrees. For the positions $\psi=0$ degrees, $\psi=90$ degrees and $\psi=180$ degrees the lobe is aligned, respectively with the directions $\theta=-4$ degrees, $\theta=0$ degrees and $\theta=+4$ degrees. Hence, during the test, the lobe oscillated between the $+4$ degree and -4 degree directions. It will be noted that the overall characteristic does not include pronounced minor lobes.

Referring to Fig. 9, reference numeral 52 denotes a "leaky wave guide of the second kind" having electric plane or *a* walls 2 and 3, magnetic plane or *b* walls 4 and 5 and end walls 15. The front wall 4 contains a plurality of transverse antenna slots 53 each extending perpendicularly to the electric walls 2 and 3. The areas of slots 53 are preferably tapered or graduated, as illustrated, for the purpose of equalizing the energies emitted or collected by the separate slots. The spacing between slots is $n\lambda_a$ where λ_a is the ether wavelength and n is equal to or less than 0.5. The guide 52 is equipped with a longitudinal rotor 14 which contains a

longitudinal slot 16 and is connected by a shaft 17 to the motor 18. As in Fig. 1, the leaky guide 52 is connected to translation device 7 by coaxial line 8 comprising inner conductor 9 and outer conductor 10. The exciter or pick-up 11 extends into the guide in a direction such that H_{01} waves radiated or received have a polarization 12 perpendicular to the guide wall 4. It will be noted that in the guide antennas of Figs. 1, 4, 6 and 7 the wave polarization is perpendicular to the scanning plane whereas in the guide antenna of Fig. 9 (and Fig. 11) the wave polarization is parallel to the scanning plane.

In operation, referring to Figs. 9 and 10 and assuming device 7 is a pulse transceiver, pulses are supplied by device 7 over line 8 to guide 52 and, for each pulse, distinct wavelets are simultaneously emitted by the rectangular apertures 53. The pulses are received after reflection at a distant target and conveyed over line 8 to transceiver 7. The maximum directive lobe of each aperture antenna 53 is not sharp and in Fig. 10 is represented by the curve 54. During the transmission and subsequent reception of the pulses, the motor driven rotor 14 causes the maximum space factor lobe 55, Fig. 10, of the linear array comprising apertures 53 to move back and forth across the effective aperture lobe and therefore causes the resultant or product lobe 56 to oscillate and scan the desired angular sector 57. The rate of sweep or scan is determined by the speed of the rotor and preferably the rotor speed and the pulsing rate are such that in transmission a large number of pulses are emitted during each oscillation of the maximum resultant lobe 56.

The angle $\cos^{-1}\frac{c}{v}$ between the array axis and the direction of maximum action is other than 90 degrees, that is, the scanning sector is not positioned broadside. Assuming, as shown in Fig. 9 that the slots 53 are spaced less than a half a wavelength, the direction of maximum action is the same as in the case of "leaky wave guides of the first kind" and no significant secondary maxima should occur. It may be noted that if the slot spacing in structure of Fig. 9 were greater than one wavelength, as in the system of Fig. 11 described below, the space factor characteristic would include two or more maximum lobes; and if it were greater than one half wavelength and less than one wavelength the characteristic may include more than one maximum lobe.

Referring to Fig. 11, reference numeral 58 denotes a "leaky wave guide of the second kind" having in its front electric plane wall 4 the longitudinally spaced circular apertures 59, and numerals 60 designate end-on polystyrene antenna elements each of which projects into, and is supported in, one of the apertures 59. The rods 60 are tapered for the purpose of securing a directive characteristic having a single maximum lobe of selected width and negligible minor lobes. As discussed below the spacing between adjacent rods 60 is equal to or greater than one wavelength and preferably about one and a half to two wavelengths, and the range of the phase velocity variation is selected in accordance with the rod spacing, or *vice versa*.

Referring to Figs. 12 and 13 the manner of determining the proper range of phase velocity variation for a given value of n, equal to or greater than 1.0, will now be explained. First of all, the velocity ratio or phase velocity characteristic k must be such, as explained below, that a phase velocity corresponding to a second mode of the wave is not established in the guide, otherwise the space factor directive characteristic, corresponding to the desired operating frequency, of the linear array comprising rods 60 would be greatly distorted. As discussed in A. E. Bowen's United States Patent No. 2,129,669, the wavelength in a rectangular air-filled guide conveying H_{01} waves is controlled by the dimension b and the limiting condition for preventing the second mode is

$$b=\lambda_a \qquad (1)$$

where λ_a is the ether wavelength.

The equation, as given in the Bowen patent, expressing the relation for λ_a, b and λ_g, is

$$\lambda_g=\frac{\lambda_a}{\sqrt{1-\left[\frac{(\lambda_a)}{(2b)}\right]^2}} \qquad (2)$$

where λ_g is the guide wavelength, or

$$\frac{\lambda_a}{\lambda_g}=\sqrt{1-\left[\frac{(\lambda_a)}{(2b)}\right]^2}=k \qquad (3)$$

letting

$$\frac{\lambda_a}{\lambda_g}=\frac{c}{v} \qquad (4)$$

and substituting λ_a for b, we have

$$\frac{c}{v}=\sqrt{1-\left[\frac{(1)}{(2)}\right]^2}=0.865=k \qquad (5)$$

Hence, as a first limitation, the phase velocity ratio or characteristic $\frac{c}{v}$ must be equal to or smaller than 0.865, as is indicated by the horizontal broken line 61 in Fig. 13.

Referring to Fig. 11, the phase shift between adjacent rods is

$$\frac{n\lambda_a}{\lambda_g}360 \text{ degrees.} \quad (6)$$

In order to get a maximum resultant at any angle θ, this phase shift must differ from 360 degrees by the quantity

$$\frac{n\lambda_a \sin\theta}{\lambda_a}360 \text{ degrees.} \quad (7)$$

That is,

$$360 \pm (n \sin\theta)\, 360 = \frac{n\lambda_a}{\lambda_g}360. \quad (8)$$

Since

$$\frac{c}{v} = \frac{\lambda_a}{\lambda_g}. \quad (9)$$

We have by substituting

$$1 \pm n \sin\theta = n\frac{c}{v} \quad (10)$$

or

$$\frac{c}{v} = \frac{1}{n} \pm \sin\theta = k \quad (11)$$

From equation (11), for each direction θ in a desired azimuthal sector and a given value of n, the velocity characteristic k may be determined. Referring to Fig 13, the curves $n=1$, $n=1.11$, $n=1.50$, $n=1.75$, $n=1.90$ and $n=2$, designated respectively by reference numerals 62, 63, 64, 65, 66 and 67, were determined in this manner. It will be observed that, for a spacing of one wavelength ($n=1$) and a range of 0.5 to 0.865 for the velocity ratio k, a scanning sector extending from $+8$ degrees to $+30$ degrees, as illustrated by line 62, is obtained without second mode effects, the sector being centred approximately on the $+19$ degree direction denoted by reference numeral 68. With $n=1$, a second mode distortion is obtained for directions less than $\theta=8$ degrees, since, for these directions the value of k exceeds 0.865. With $n=2$, a 29 degree ($\pm\theta=14.5$ degrees) scanning sector extending broadside and having its mean direction perpendicular to the plane of the rods 60 may be secured by dimensioning the velocity variation rotor 14 so that k varies over the range 0.23 approximately to 0.76 approximately. In accordance with the invention, the dimensions of the rotor 14 and especially of the slot 16 are selected to give the proper velocity variation for a given constant operating frequency, a given value of n and a given desired angular scanning sector $\pm\theta$, preferably but not necessarily, centred on the $\theta=0$ direction. In this connection, it may be noted that the proper width of slot 16 in rotor 14, Fig. 3, or the proper width and proper depth of slot 27 in rotor 25, Fig. 3, for securing a desired variation in k, may be easily determined experimentally, inasmuch as rotor 14 without the slot 16 or rotor 27 without the slot 27 produce no velocity variation.

The operation of the system of Fig. 11 is believed to be apparent in view of the description given above relative to Fig. 9. Briefly, pulses are supplied by device 7 over line 8 to guide 58 and, for each pulse, distinct wavelets are simultaneously emitted by the rods 60. Assuming $n=2$, during the transmission and subsequent reception of the pulses, the motor driven rotor 14 causes the primary space factor lobe to oscillate across the 29 degree sector, Fig. 13, and across the major lobe of each rod 60. As shown by the dash-dot lines 69 and 70, Fig. 13, which traverse the lines 65, 66 and 67, with the primary maximum lobe at one extremity of the scanning sector, a secondary maximum lobe occurs at the other extremity. Thus for $n=2$, assuming the primary lobe is moving from the $\theta=0$ direction to the -15 degree direction, a secondary maximum lobe appears at the $+15$ degree as the primary lobe reaches the -15 degree direction. The minor lobes of the directive characteristic of each rod 60 should have negligible intensities; and the shape of the rod major lobe should be such that, during the scanning, only one maximum space factor or array lobe intercepts at any given instant the rod major lobe whereby unambiguous scanning is secured.

Although the invention has been explained in connection with certain embodiments, it should be understood that it is not to be limited to the embodiments described, inasmuch as other apparatus may be satisfactorily employed in practising the invention. In particular, instead of a velocity variation device of the

rotor type, velocity variation devices of the plunger or reciprocating type may be employed. Thus the velocity variation device may comprise a member having a flat surface extending inside the guide parallel to an *a* or *b* guide wall, and plunger means for cyclically moving the aforementioned flat member or false guide wall relative to one pair of stationary guide walls. Moreover, the invention may be successfully employed in systems utilising guided wave components other than H_{01} waves.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A directional antenna provided with a wave transmission channel adapted to radiate or receive the waves at points along its length and to which a beam-sweeping action is imparted by cyclically varying the phase velocity of the waves within the transmission channel.

2. A directional antenna according to claim 1, in which the variation in phase velocity is produced by cyclically varying the effective cross-sectional area of the wave transmission channel.

3. A directional antenna provided with a wave guide adapted to radiate or receive the waves at points along its length and a movable member interacting with the waves within the wave guide and adapted by its movement to produce a cyclical variation in the phase velocity of the waves and thereby impart a beam-sweeping action to the antenna.

4. A directional antenna according to claim 3, in which the movable member comprises a rotor disposed within the wave guide, and adapted by its rotation to produce a cyclical variation in the effective cross-sectional area of the wave guide.

5. A directional antenna according to claim 4, in which the rotor comprises a substantially cylindrical or partly cylindrical member extending longitudinally within the wave guide and provided with a longitudinal slot or having a longitudinally extending flat surface.

6. A directional antenna according to claim 5, in which the rotor has any one of the three cross-sectional shapes illustrated in Fig. 3 of the accompanying drawings.

7. A directional antenna according to any of claims 4 to 6 utilising a substantially rectangular wave guide, in which the rotor extends longitudinally within the wave guide adjacent an electric plane wall or side thereof which is opposite an electric plane wall provided with a longitudinal antenna slot for radiating or receiving the waves.

8. A directional antenna according to Claim 7, in which the magnetic plane walls and one of the end walls of the wave guide are extended outside the longitudinal antenna slot to form a triangular structure having a wave emitting or receiving aperture extending substantially perpendicularly to the mean direction of radiation or reception of the waves.

9. A directional antenna according to claim 8, in which the aperture is surrounded by flared sides and end pieces so that the structure forms a horn antenna.

10. A directional antenna according to any of claims 4 to 6 utilising a substantially rectangular wave guide, in which the rotor extends longitudinally within the wave guide adjacent an electric plane wall or side thereof and in which the waves are radiated or received through apertures spaced longitudinally in an adjoining magnetic plane wall of the wave guide.

11. A directional antenna according to claim 10, in which the apertures in the magnetic plane wall comprise transverse slots extending perpendicularly to the electric plane walls of the wave guide and the areas of which are progressively varied so as to equalize the wave energy components emitted or collected thereby.

12. A directional antenna according to claim 11, in which the spacing between the slots is $n\lambda_a$, where λ_a is the wave length as measured in the air and n is equal to or less than 0.5.

13. A directional antenna according to claim 10, in which the waves are radiated or received by means of rod antenna elements projecting from the apertures in the magnetic plane wall.

14. A directional antenna according to claim 13, in which the rod antenna elements are tapered for the purpose described.

15. A directional antenna according to claim 13 or claim 14, in which the rod antenna elements are formed of polystyrene.

16. A directional antenna according to any of claims 13 to 15, in which the spacing between the rods is $n\lambda_a$, where λ_a is the wave length as measured in the air and n is equal to or greater than 1.

17. A directional antenna according to claim 16, in which the phase velocity characteristic, as herein defined, is not greater than 0.865, and in which this characteristic and the spacing between the rods are so selected that at a given operating frequency the mean direction of radiation or reception of the waves is substantially perpendicular to the longitudinal

axis of the wave guide.

18. A composite antenna structure for radio location and like systems comprising a transmitting antenna according to claim 7 and a receiving antenna provided with a similar longitudinally slotted wave guide, of similar structure but without a rotor; the two antennas being arranged one above the other with the walls of the wave guides containing the longitudinal slots disposed in a common plane.

19. A composite antenna structure for radio location and like systems comprising a transmitting antenna according to claim 8 or claim 9 and a receiving antenna provided with a longitudinally slotted wave guide of similar construction but without a rotor together with a similar triangular structure, the two antennas being arranged one above the other with the wave emitting and receiving apertures of the triangular structures disposed in a common plane and the wave guides extending towards opposite ends of the wave emitting and receiving apertures.

20. A composite antenna structure for radiolocation and like systems comprising a receiving antenna according to claim 7 and a transmitting antenna which is provided with a longitudinally slotted wave guide of similar structure but without a rotor, the two antennas being arranged one above the other with the walls of the wave guides containing the longitudinal slots disposed in a common plane.

21. A composite antenna structure for radiolocation and the like comprising a receiving antenna according to claim 8 or claim 9 and a transmitting antenna which is provided with a longitudinally slotted wave guide of similar construction but without a rotor together with a similar triangular structure, the two antennas being arranged one above the other with the wave emitting and receiving apertures of the triangular structures disposed in a common plane and the wave guides extending towards opposite ends of the wave emitting and receiving apertures.

22. A directional antenna constructed and operating substantially as herein described with reference to Figs. 1 and 2, or with reference to Figs. 4 and 5, or Figs. 9 and 10, or Figs. 11 to 13 of the accompanying drawings.

23. A composite antenna structure for radio location and like systems constructed and operating substantially as herein described with reference to Figs. 6 to 8 of the accompanying drawings.

Dated this 13th day of July, 1944.

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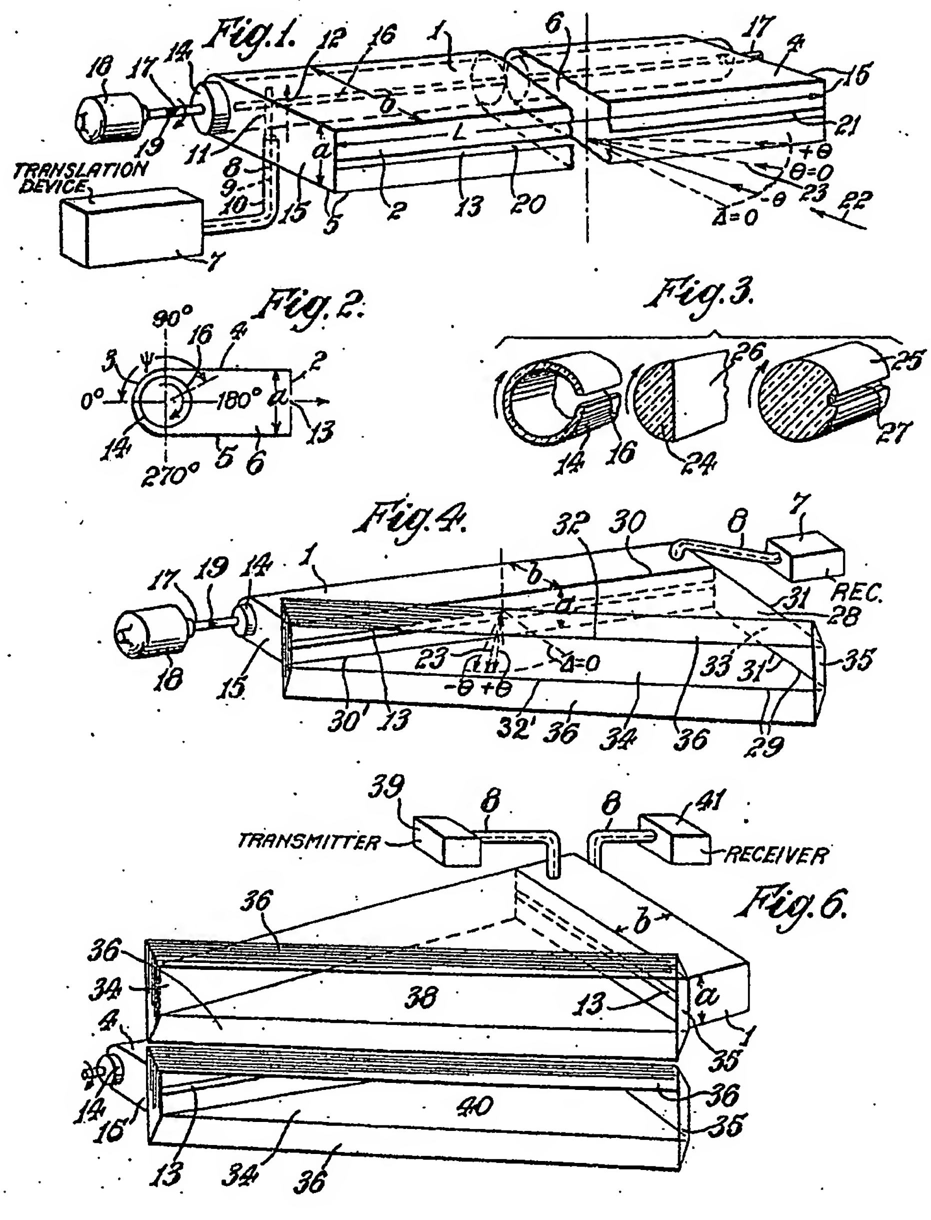

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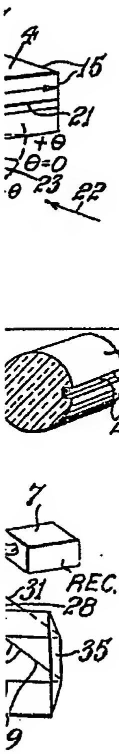


Fig.9.

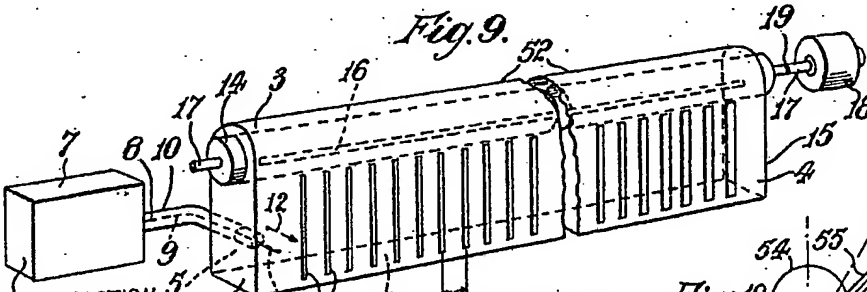


Fig.10.

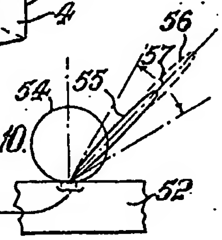


Fig.11.

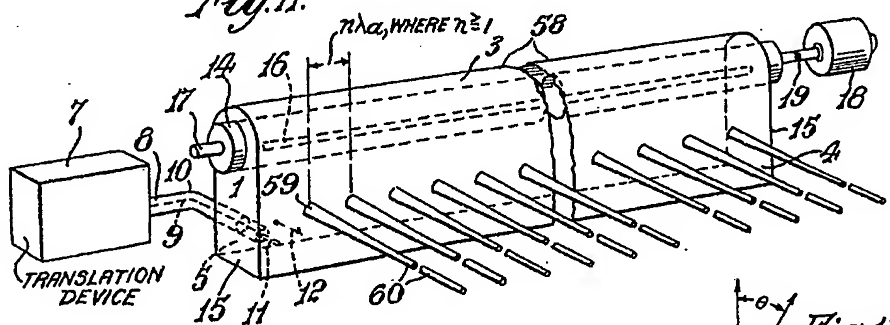


Fig.12.

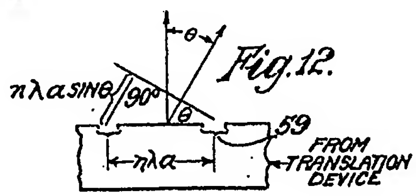
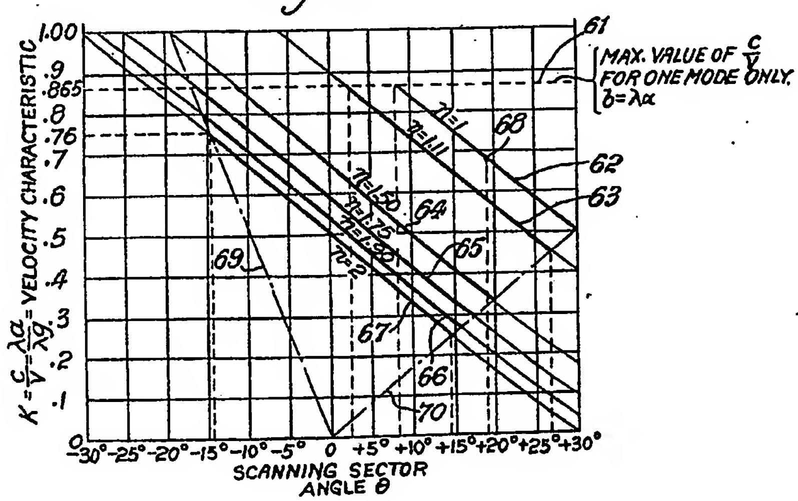


Fig.13.



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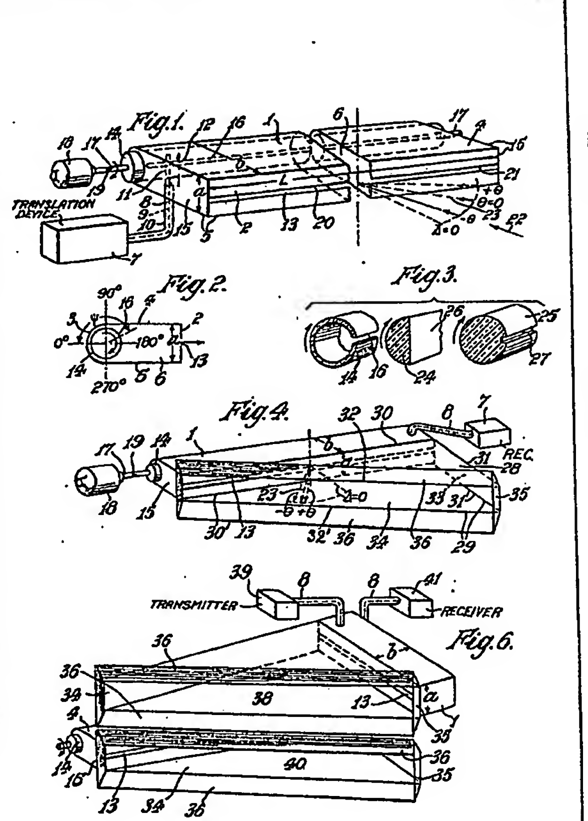

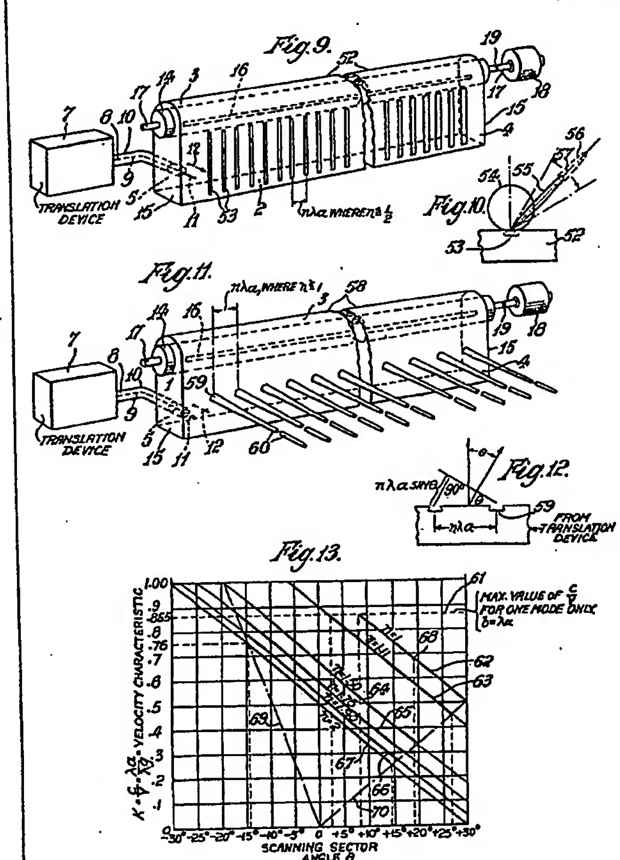

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